Beaches and Migrating Sand – Tutorial Script

Let's return to the beach and study further the movement of beach sand – Where does it come from? How does it move and change with the seasons? And where, besides our swim suits, does it ultimately end up?

This image breaks the coast into zones – **offshore, nearshore, foreshore, and backshore**. The **surf zone** is the point at which waves first feel bottom as they enter shallow waters. As waves move across the surf zone, they push sand onto the shore in the summer, when wave energy is low, and remove it from the land during the winter, when wave energy is high, storing it offshore in a **longshore bar**. We call the area on the beach where the sand piles up at its highest, the **berm**. In this picture, the berm piles up at the base of the wave-cut cliff. The part of the berm that is alternately covered and uncovered by the high and low tides is called the **intertidal zone**. This image of a beach shows the area behind the **backshore** is a wave-cut cliff with a terrace atop it. That means this is most likely an uplifting coastline with high rates of erosion. This image of Ocean Beach shows a very different type of coast, where the berm backs up into a sand dune system. This shoreline is sinking and is displaying depositional features. You can identify the intertidal zone in this image because you can see the high tide line at the base of the dunes and the low tide line where the current water level is. Along rocky shorelines, such as this picture of Rodeo Beach, the steeper cliff faces create a very different look to the intertidal zone. The solid rocks allow for organisms to attach and reef communities to develop. In the sandy shoreline, all the intertidal organisms live in or under the sand.

The main effect of waves hitting shore at an angle is the movement of sand and water along the beach. We call the movement of sand, **longshore drift**, the water, **longshore current**. What direction does the sand and water move? In the opposite direction from which the waves are coming. Remember these waves are coming from far-distant storms potentially thousands of miles away as discussed in the wave video tutorial. Because these storms are concentrated at the polar front northward of California, the direction of longshore drift is usually southward. The same is true for the East Coast of the United States – most of its storms are to the north, so most of the longshore current is to the south. However, that can change locally due to the shape of the coastline or regionally due to seasonal storm changes. For example, during the summer, hurricanes are a bigger issue in the Atlantic Ocean and Gulf Coast, so as this picture shows for a barrier island in Texas, the direction of longshore drift in summer months is northward, in winter months southward. This image of Cape Cod shows a spit moving southward on the southern half of the Cape, and a spit moving northward and hooking inward on the northern half of the cape. Why? The shape of the coastline means that waves will feel bottom first in the middle of the cape and then bend in different directions on either side. Again, refer to the refraction discussion in the waves video tutorial. This close up satellite image of Point Reyes just north of San Francisco shows a similar phenomenon. The white sands displayed here are part of Limantour Spit, which forms from sand moving northward. Why? Waves coming from the north will migrate along this part of the coastline and then as they hit the headland they will bend around it, eventually spiraling inward so they push sand into the embayment from the southern side.

Not only does sand move along the coast with the wave-produced longshore current, but it also moves on and offshore with the seasons as previously mentioned, due to the differences in energy of winter waves versus summer waves. This image shows two different beach profiles – the solid blue line represents a beach with the highest berm, produced after many months of summer waves. The dashed red line shows what the beach looks like at the end of the winter season just before the winter storms end. Much of the sand has been pulled offshore and sits underwater in offshore bars. These offshore bars are not visible, but they are noticeable to those who swim or surf along the California Coastline in the spring months, because a short paddle offshore through deeper water will eventually land you back in shallow water where you can stand up on the bar. Here is a picture of a beach at the time of year when its berm is highest. When would that be? Just before the winter storm waves arrive and summer waves have had months to push sand up to the beach. October. Here's a beach picture showing the beach with most of its sand removed. Clearly if you plan to spend time on a beach, you better plan your excursions with the seasons. Fall is best for big beaches – Spring for rocky.

Pause now.

So sand moves along the shore by longshore current and is pushed on and off the shore with the seasons. Now let's talk about where this sand actually comes from. All beach sand **ultimately** comes from two sources. Most, 90%, comes from erosion of the backcountry, carried to the shorelines by rivers. The rest mostly comes from the erosion of local coastal rocks – cliffs, headlands, wave-cut benches, etc. What happens when coastal cliffs are covered by concrete in an attempt to diminish erosion? Beaches dwindle – waves can get closer to the shore – and the risk of cliff undercutting increases. The same is true when we dam rivers. Sediment destined for beaches remains trapped behind dams, and downshore beaches dwindle. How do we solve these problems? Import sand from elsewhere. During the summer months, sand and gravel companies mine the sands that are trapped behind dams in the mountains and carry that sand to the beaches, where local residents and cities pay to have sand redistributed. Minor amounts of sand also come from local reef erosion. If you live in an area where there are extensive coral reefs, these can be a major source of beach sands. In California, we have no coral reefs. But some small amounts of our sand might be composed of shells. However, these will never be a major source for us.

All beach sand **ultimately** ends up in two sinks. It's either sucked down a submarine canyon or it's blown on land as a sand dune where it is later buried and turned to sandstone. When sand is carried down a submarine canyon by turbidity currents or gradual raining down the sides of the canyon walls, it ends up in a pile at the base of the canyon on the deep sea floor – now part of the continental rise or apron of sediments that collect at the base of the continental slope. In between source and sink, the longshore current distributes sand along the beaches.

This Google Earth image of the California offshore continental shelf shows a few important submarine canyons that siphon sand off our beaches. This double-headed canyon is known as the Pioneer Canyon and it is carved by sand avalanches (or turbidity currents) that are caused by sands pulled offshore by the rip currents that form off Devil's Slide. You can imagine here the longshore current moving south and colliding with and deflecting offshore by this headland, then directing sand toward this canyon. Further south we see a few more canyons including one of the most well-studied and largest submarine canyons in the world – the Monterey Bay Canyon.

This image of the Southern California coastline shows a number of beach compartments in which sand enters the longshore current system via rivers, grows in size as it is carried down the shore, collecting more river sand as well as sand from local coastal erosion, and then is pulled offshore into submarine canyons.

You would expect to find the largest beaches just north of the canyons where the maximum amount of sand has collected. You would expect to find the smallest beaches just southwards, after its been removed by canyons and before new sands have been added by rivers. This sidescan sonar image shows the different offshore canyons that act as major sinks pulling the sands offshore and carrying them to the bottom of the seafloor. Let's look more closely at the area between Santa Monica and San Pedro. Based on the compartments shown, we would expect this area to have little sand, as most of it would have been drawn off by the Redondo Canyon to the north. This area is a rocky headland known as the Palos Verdes Peninsula. The Redondo Canyon acts as a major sink preventing sand from migrating around the peninsula.

Pause now.

Since ocean-front property has the greatest value in our real estate markets, let's explore deeper the interactions and consequences of building coastal structures within the longshore current system. This image highlights four different kinds of structures that can be built along a shoreline. In the top left, we have a concrete wall that extends perpendicularly to the shoreline. We call this structure a **groin**. When there are two of them running parallel to each other and on opposite sides of an embayment opening, we call them **jetties**. When we build this structure parallel to the shore and just off the shore, we call it a **breakwater**. When the structure is built parallel to the shore and on the shore, we call it a **seawall**.

Groins are purposefully placed to block sand movement in the longshore current system. This blockage allows a large beach to form on the upcurrent side, which is usually the intention. The result, however, is that waves that reach the beach downcurrent of the groin have no sand – they pick up and move the sand that's there, but don't replenish it. Sand is gradually eroded, and the coast retreats. Water gets deeper on this side of the groin which allows the waves here to be stronger. These waves have more erosive power and continue to erode inland and downward, undercutting the groin. Remember from the waves video tutorial that anything that sticks out along a coast will cause waves to refract around and into it, focusing their energy on eroding the object. So this structure will have to be regularly maintained. Some areas have installed regularly placed groins, in the hopes of minimizing coastal erosion. You can see that the sand piles up on the upcurrent side and erosion is increased on the downcurrent side. Here erosion must be continually fought with beach nourishment to prevent erosion of the structures that sit just behind this groin.

What about jetties? These are also built to get in the way of longshore current, but in this case it's an attempt to prevent a spit closing off the mouth of a harbor or inlet. The results are similar to a groin's – sand piles up on the upcurrent side, and erosion increases on the downcurrent side. This image of barrier islands on the East Coast shows what happened when jetties were built across the Ocean City Inlet. You see the large bulge on the north side of the top jetty and the thickening of that portion of the barrier island complex, while the south island, Assateague, has been thinned and, as all barrier islands behave, moved further inland by gradual sand migration. Communities to the north are maintained by dredging sand from the jetty build up and redistributing it northwards along the coast. Without this dredging, sand would enter the harbor and fill the inlet mouth and Fenwick Island would keep migrating coastward as Assateague does – which is fine if nothing's built upon it, but with extensive seafront property, migrating islands of sand present a problem. Meanwhile, the jetty on the south is being extended yearly inland to maintain its connection to Assateague. And you can imagine how deep it must be in the water south of this jetty. Maintaining this jetty is more and more difficult every year because it is being undercut and eroded.

Often these structures are installed initially in lieu of dredging. But eventually dredging is necessary to maintain them. These are dredging ships in San Francisco Bay that are used on a regular basis to deepen the shipping channels between the Golden Gate Bridge and the Alameda Shipyards.

Let's move on to breakwaters, such as this one in Santa Barbara Harbor. Breakwaters are made to break the energy of the waves and create a calm harbor behind them. However, other results include a buildup of sand around and into the harbor and a loss of sand and increase of erosion on the down current side. This increased erosion can threaten coastal structures down current such as roads and buildings. In Santa Barbara, they chose to have dredging ships work 24 hours a day, 7 days a week – there are now two of them, to dredge the sand that piles up in the harbor and move it back down the coast to return it to the longshore current system. Such a problem is faced locally in Half Moon Bay, where Highway 1 was significantly eroded after the breakwater installation and had to be moved inland. And the waves that hit the outside of the breakwater erode the sand from under the breakwater, because that's where their energy is deflected. That means the water just off the breakwater is deeper – waves have higher energy because they make it closer to the shore before losing it – and the waters here can be quite dangerous. These waves can also be so large that they crash over the breakwater with huge force and can cause damage to the boats on the other side. And, of course, the breakwater must be regularly maintained as it's being undercut daily.

Seawalls are the structure of last resort used to prevent erosion of parking lots, cliffs, and homes built right along the edge of the water. Remember that erosion of the coastline rock is one source for sands along a beach. If this erosion is prevented, beaches shrink. Wave energy will instead erode downward. Slopes get steeper and steeper in front of the walls – beaches completely disappear – and eventually the walls get undercut. Unfortunately when they fail with a heightened slope in front, the consequent landslide and associated damage is much more intense than if they had been gradually eroded. If rip rap is used instead of a seawall, when the underlying sand is carved out, the rip rap will sink down and more can be added on top. It's an easier structure, therefore, to maintain, but it still creates very steep beach fronts with high wave energy attacking the structure. Due to rip rap installation along some of these hillsides, the normal erosion rates are increased on the unprotected slopes in between.

What to do? States can enact policies that prevent the building of new permanent structures along all or portions of a coastline. As old structures fall apart, they can be removed. Eventually in these areas, the shoreline can return to its natural state, and those who choose to live along the coast will have to be prepared to handle the constant shifting of sands and the gradual erosion of headlands and cliffs. The alternative is for some areas to be protected at a large cost to the communities that finance the maintenance of the structures and with large erosional consequences elsewhere. Wave energy won't disappear. It can only be deflected. If you plan to build a coastal structure, at the very least you should understand what these consequences and long-term costs will be.

Pause now.
For more information and more detail, continue on to the next video in this series.

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Coastal Video Series:
Part I: Coastlines
Part II: Beaches and Sand Migration
Part III: Estuarine Mixing
Part IV: San Francisco Bay

Beaches and Sand Migration
Produced by Katryn Wiese
City College of San Francisco

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